Industrial robot

TECHNICAL FIELD

5   The present invention relates to an industrial robot com-
     prising a manipulator and control equipment where the mani-
     pulator has three arms, each arm having a linkage suppor-
     ting a movable platform. The control equipment comprises
     drives and means including a microprocessor and software
10   for driving and guiding the manipulator in the desired
     manner. To achieve the desired movement of the platform,
     the linkages comprise links or rods that are articulately
     connected between the platform and the arms. Each joint
     allows a movement in three degrees of freedom. The arms are
15   fixed to stationary actuators that allow a movement in one
     degree of freedom. This movement comprises both rotation
     and translation. The task of the platform is to directly or
     indirectly support tools or objects for movement, measure-
     ment, processing, machining, joining, etc.
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BACKGROUND ART

     A robot comprising more than one arm and where at least two
     arms each form chains of joints between the actuators of
25   the robot and the platform that is to be manipulated is
     called a parallel-arm robot or a parallel-kinematic robot.
     For a fully extended parallel-arm robot for movement of a
     platform with three degrees of freedom (e.g. in directions
     x, y and z in a Cartesian system of coordinates), three
30   parallel-working arms are required. If all six degrees of
     freedom of the platform (x, y, z and the tool orientation)
     are to be manipulated, six parallel-working arms are re-
     quired. Each such arm comprises an upper arm and a lower
     arm. In several applications, a manipulation with a combi-
35   nation of degrees of freedom for positioning and degrees of
     freedom for orientation is desired. One class of such app-
     lications is interior work in narrow spaces. In that case,
     it is often desired to have a robot with two degrees of

freedom for tool orientation and only one degree of freedom
for radial positioning.

To obtain a rigid arm system with a large loading capacity
5   and a low weight, the lower arms of the parallel-kinematic
manipulator, nearest the manipulated platform, shall con-
sist of six links in total, which only transfer compressive
and tensile forces. For a manipulator with three degrees of
freedom and three arms, this means that these six links
10   must be distributed among the arms and this can only be
done with two different combinations 2/2/2 or 3/2/1.

To more readily describe parallel-kinematic robots compri-
sing linkages, some definitions of different linkages are
15   introduced here:
   • **Link**: A link is a member that movably joins two
      elements and that, at each end, allows movement in
      three degrees of freedom. It usually consists of a
      rigid elongated member such as, for example, a rod
20   that has a ball joint at each end. The link holds the
      elements at a definite distance from each other and
      absorbs only tensile or compressive forces. Thus, a
      link transfers no torsional movements.
   • **Double link**:   A double link is a member that
25   movably joins two elements, that at each end allows
      movement in three degrees of freedom, and that trans-
      fers a moment in a plane between the elements. The
      double link consists of a quadrangle with, for exam-
      ple, two links, according to the above, that form a
30   first pair of links and the elements that form the
      second pair of links. In a special case, the double
      link is a parallelogram, in which case the two ele-
      ments are forced to move in parallel with each other.
      Since all joints allow movement in three degrees of
35   freedom, this implies that the double link may be
      twisted. Thus, the double link needs help from other
      linkages to remain plane.

- **Locked double link**: A locked double link is a member that movably joins two elements that, at each end, allows movement in two degrees of freedom. The locked double link consists of a double link according to the above, wherein at least one diagonal is locked. This is achieved, for example, by introducing in the quadrangle an additional link that is not parallel to any of the other links. This prevents the elements from being displaced, but still the locked double link may be twisted.

- **Triple link**:   A triple link is a member that movably joins two elements, that at each end allows movement in three degrees of freedom, and that transfers a moment in two planes between the elements. The triple link usually consists of two double links, oriented in different planes, with one common link. In a special case, the triple link comprises a space parallelogram consisting of three parallel links of equal length. Such a space parallelogram may be twisted but maintains the elements oriented in parallel planes.

- **Triangle**:   A triangle is a member that movably joins two elements and that at one end (the base) allows movement in one degree of freedom and at its other end allows movement in three degrees of freedom. The triangle consists, for example, of a torsionally rigid member that, at its base, is journalled to a first element through an axis and at its other end is journalled to a second element by means of a ball joint. A triangle may also consist of two links according to the above, where one of the joints is common.

In the following text, an arm for a robot shall mean a linkage supported by a supporting arm. By the concept **supporting arm** is to be understood a torsionally rigid member that movably joins two elements together and that, at both ends, allow movement in one degree of freedom. The supporting arm consists, for example, of a tube with a fork arranged at each end through which an axle passes. In a

special case, the axles are parallel whereby the elements
joined by the supporting arm are allowed movement in one
plane only. It should be mentioned that the movement com-
prises rotation as well as translation. The supporting arm
5   may, from one element to the other, transfer both tensile
and compressive forces, torsional moment and bending mom-
ent.

When a working range in the form of a sphere or an ellip-
10   soid is required, serial kinematics is currently used,
wherein the first three joints (axes) are substantially
responsible for the positioning of the tool and the other
axes (nearest the tool) are substantially responsible for
the orientation of the tool. The most commonly used kine-
15   matics is thus the following: Axis 1 rotates the whole
robot structure, axis 2 rotates a first arm in the vertical
plane, axis 3 rotates a second arm, also in the vertical
plane, axis 4 rotates the tool around an axis in the centre
of the second arm, axis 5 rotates the tool around an axis
20   perpendicular to axis 4, and axis 6 rotates the tool around
an axis perpendicular to axis 5. This serial construction
of the robot results in the following problems:

- The robot becomes heavy, which limits its speed and
25   which necessitates expensive and energy-consuming
actuators (motors). If, in addition, the robot is to
be mounted as a slave on a master manipulator in
order, for example, to guide the robot into narrow
spaces, a heavy slave-type robot gives a still heavier
30   and more expensive master manipulator.
- The robot becomes pliant and when objects or tools are
moved, a undesired oscillating motion is obtained
along the path along which the movement is to be made,
and when the movement is to be stopped, so-called
35   overshoots arise. This problem is increased further in
case of a master/slave configuration, whereby also the
performance of the master manipulator is deteriorated.

- The robot becomes resilient when forces are to be ge-
  nerated between the tool and the object, which is im-
  paired in a master/slave configuration.

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- For the serially mounted movable actuators with asso-
  ciated measurement sensors, movable cabling is requi-
  red, which reduces the reliability of the serially ki-
  nematic robots.

- It is difficult to obtain a high accuracy of the robot
  without providing very expensive solutions with preci-

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  sion components and precision assembly of the robot.

- Because of temperature-dependent arm lengths and geo-
  metrical relations of the serially constructed robot,
  the tool positioning becomes temperature-dependent.

15   All of these limitations with currently used serial kine-
     matic robots can be eliminated with a parallel-kinematic
     robot that is driven by parallel-working linkages, which do
     not need to support one another.

20   One example of such a robot is previously known from the
     patent publication WO99/58301. This robot has, in its basic
     design, three degrees of freedom and comprises three link-
     ages that are connected in parallel between three rotating
     actuators and one manipulated platform. Each linkage con-
25   sists of a pivoting arm, which via two parallel-working
     articulated rods is connected to the manipulated platform.
     At both ends of the articulated rods, joints with two or
     three degrees of freedom are positioned. The parallel kine-
     matic robot thus obtained has a toroidal working range
30   around a base platform, on which the actuators are mounted.
     The manipulated platform will not change its angle of in-
     clination during the positioning and the extent of the
     working range above and below the robot is limited by the
     parallel articulated rods between the lower arms and the
35   manipulated platform. For this reason, the robot cannot be
     designed for a working range in the form of a sphere or an
     ellipsoid.

A parallel-kinematic manipulator that is capable of chang-
ing the inclination of the manipulated platform and that
has a possibility of providing a working range in the form
of a sphere or an ellipsoid is described in US patent spe-
5   cification US 4,651,589. Two elements are here connected to
at least three legs that are placed in separate planes. The
legs each consist of two parts, each part being connected
at one end to the other part of the same leg by a spherical
connection and at the other end to one of the two elements,
10   however not the element to which the other part of the same
leg is connected, by a rotational connection. However, this
structure provides a working range that is barely half an
ellipsoid and that is therefore not sufficient to build a
robot capable of working in all directions with a working
15   range corresponding to a whole ellipsoid or sphere. To sum
up, the manipulator disclosed in US 4,651,589 has the fol-
lowing limitations.

     • A small working range (maximum half an ellipsoid).
20   • Since the legs are working in different planes, all
       the axes of rotation of the driving motors will have
       different directions, which makes it impossible to
       have two parallel or coinciding motor shafts. However,
       this is necessary for obtaining a simple motor drive
25   that is not space-demanding, which is especially im-
       portant when the manipulator is to be used as a wrist
       with transmissions between, on the one hand, motors at
       one end of a robot arm and, on the other hand, the
       wrist at the other end of the same robot arm.
30   • The structure is only intended for manipulators with
       rotating motors that, via pivoting arms, give the ma-
       nipulated platform its movements. In several applica-
       tions, it is desirable to use linear actuators without
       pivoting arms, which is not possible with legs working
35   in different planes.

These limitations, which are fundamental for applications
in practice, are not present in the parallel-kinematic ro-

bot according to the present invention, which is due the
following facts:

- Two linkages (corresponding to legs in US 4,651,589)
  are working in a common plane.
- These two linkages may therefore, nearest the manipu-
  lated platform, each have a set of articulated rods
  mounted on the manipulated platform with joints where
  a line through these joints (called lead line) of one
  set of articulated rods becomes parallel to the corre-
  sponding lead line of the other set of articulated
  rods.
- These parallel lead lines then provide a possibility
  of having two rotating actuators with parallel or co-
  inciding axes of rotation, which via pivoting arms ma-
  nipulate the two linkages.
- This configuration of the motor shafts provides a pos-
  sibility of obtaining a working range of +/- 180 de-
  grees and even +/- 200 degrees, which results in a
  working range of the robot corresponding to a whole
  sphere or ellipsoid. No previously known parallel-
  kinematic structure has such a large solid-angle work-
  ing range.
- In the case of coinciding axes of rotation, in addi-
  tion, the manipulated platform may be rotated an in-
  finite number of turns around the axis of rotation
  which is then common to the two motors, which makes it
  possible always to program the robot to take the nea-
  rest path between two positions/orientations of the
  manipulated platform (it is not necessary to rotate
  back one turn if, for example, one position lies at
  the end of a turn and the next position lies at the
  beginning of the same turn).
- Furthermore, with coinciding axes of rotation, these
  may be driven with coaxial tube transmissions, which
  enables having the driving motors at one end of a
  robot arm and the axles for driving the two linkages
  at the other end of the robot arm.

- The parallel lead lines for the two linkages then enable the introduction of a third linkage with a set of articulated rods that has a lead line that is perpendicular to the lead lines of the first two sets of articulated rods.

- This in turn provides a possibility of introducing a third motor with an axis of rotation that is perpendicular to the axes of rotation of the other two motors. In this way, a single belt transmission or a tube transmission with a bevel gear pair may be used in a wrist for transmitting motor torque from the motor at one end of the robot arm to the third linkage.

- The parallel lead lines for the two sets of articulated rods then provide a possibility of introducing, for the set of articulated rods of the third linkage with a lead line that is perpendicular to the lead lines of the first two sets of articulated rods, three articulated rods, whereby a freely rotatable motor for the third linkage will always be controlled by the other two motors such that the third linkage ends up midway between the other two linkages, which gives an optimal kinematic configuration, both with regard to the magnitude of the working range and the rigidity and performance of the robot.

- In addition, the parallel lines for the two linkages provide a possibility of mounting the sets of articulated rods with parallel lead lines on linear actuators to obtain an optimum performance in one plane. By then mounting the third set of articulated rods, with a lead line perpendicular to the other lead lines, on a third linear actuator, either directly or via a pivoting arm, optimum performance are also obtained in space between the linear actuators.

With this parallel-kinematic configuration, a robot is obtained which has all the advantages that are characteristic of a parallel-arm robot with six links to the manipulated platform and which therefore solves the problems for serial

arm robots previously described. At the same time, an agi-
lity, as great as that of a serial anthropomorphic robot,
is imparted to this robot, which implies that it may be
used, for example, in narrow spaces. However, the agility
5   enables this robot structure to be utilized in other appli-
cations as well. A few examples of areas of applications of
parallel-kinematic robots, composed according to the struc-
ture described in this patent document, will be given be-
low:

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- Arc welding, especially in master/slave configura-
  tions, for example in ships' modules.
- Spot welding, for example in wheel housings.
- Gluing, cementing, painting, for example inside engine
15   compartments, boots, fuselages.
- Assembly, for example inside car bodies in a
  master/slave configuration.
- Measurement, for example in engine blocks, gearbox
  casings and car bodies.
20 - Grinding, deburring, milling, boring, etc., for
  example in engine blocks, gearbox casings, certain
  casting.
- Laser cutting, water cutting, for example in car and
  aircraft components.
25 - Machining, where the robot is used for inserting and
  withdrawing objects in various types of machines, for
  example multi-operation machines, foundry machines,
  punches and high-pressure presses.

30 SUMMARY OF THE INVENTION

The object of the present invention is to suggest ways and
means of producing a parallel-kinematic robot that exhibits
a large working range and that prevents the arms of the ro-
35 bot from being subjected to unfavourable forces. This is
achieved by an industrial robot with a manipulator compri-
sing a stationary element, a movable element and three arms
interconnecting the elements, each arm having a supporting

arm and a linkage supported by the supporting arm, the mo-
vement plane of a central arm being adapted to intersect
the movable element upon all movements.

5   From a first aspect of the invention, the manipulator com-
prises a linkage that allows the movable element a movement
in space along a spheroid where the radius is varied and
with rotatable arms. From a second aspect of the invention,
the manipulator comprises a linkage that allows the same
10 movement but with supporting arms, the movement of which
involves translation. In a special case, a straight linear
translation is referred to.

The manipulator, which is common from all aspects, compri-
15 ses a first supporting arm, a second supporting arm, and a
third supporting arm. The second supporting arm will be re-
ferred to below also as the central supporting arm. Besides
being journalled about a first axis, around which the drive
system is arranged, this central supporting arm is also
20 freely journalled about a second axis arranged substantial-
ly in a normal plane to the drive shaft. The method for im-
parting to the central arm only small transverse forces
comprises adapting the central arm, by connections to the
other arms, to adopt a position in between these.
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The invention comprises robots that are composed of a par-
allel-kinematic arm system driven by actuators. The arm
system comprises three parallel-working linkages (A, B, C)
connecting the actuators (10, 11, 12B) to the platform (31)
30 that is to be manipulated. Nearest the manipulated platform
(31), the linkage comprises articulated rods (16, 17, 18,
19, 20, 21) and it is the configuration of these articula-
ted rods together with the configuration of the actuators
(10, 11, 12) and the manipulated platform (31) that gives
35 the robot its unique properties. To lock all of the six
degrees of freedom of the manipulated platform, a total of
at least six articulated rods are used. In this way, each
articulated rod will only need to transmit tensile and com-

pressive forces, which enables the articulated rods to be
made very rigid, light and accurate.

5   The linkages are mounted on the platform (31) by means of
       joints (23, 24, 26, 27, 29, 30) having one, two or three
       degrees of freedom. The articulated rods are distributed
       such that each linkage comprises at least two articulated
       rods for forming sets of articulated rods (16, 17; 18, 19;
       20, 21). To obtain as small forces as possible in the ar-
10   ticulated rods with respect to torques of the platform
       (31), those joints that have the same linkages are mounted
       as far away from each other as possible on the platform. A
       set of articulated rods associated with the same linkage is
       mounted with a set of joints (23, 24; 26, 27; 29, 30) on
15   the manipulated platform (31). At the other end, the arti-
       culated rods of at least two of the three sets of articula-
       ted rods (16, 17; 18, 19) are mounted on a common joint
       (22, 25). In the case where the joints between one set of
       articulated rods and the platform only have one degree of
20   freedom, the axes of rotation of those joints (23, 24; 26,
       27; 20, 21) that belong to the same set of articulated rods
       are to coincide. The common joint (22, 25, 28) for a pair
       of articulated rods shall have two or three degrees of
       freedom and the two or three axes of rotation of a common
25   joint should coincide in order that the kinematic model of
       the robot shall not be too complex. To obtain the most
       favourable load picture in the common joint, those articu-
       lated rods that are mounted thereon should point inwards
       towards the centre of the joint, where the two or three
30   axes of rotation intersect each other.

       The common joint (22, 25, 28) for a set of articulated rods
       may be mounted either on a pivoting arm (13, 14, 15) or on
       a carriage (40, 41, 42) moving along a path (3A, 3B). The
35   pivoting arms and the carriages are driven by actuators
       (10, 11, 12) which, via the three linkages (A, B, C), give
       rise to a combined transfer and rotary movement of the
       manipulated platform (31).

Based on this fundamental design of a parallel-kinematic
robot, the invention comprises a number of advantageous
embodiment.

5   The inventive comprises the feature that in two of the
three sets (16, 17; 18, 19) of articulated rods, the links
included are mounted on pivoting arms (13, 14) with the aid
of a joint (22, 25) which is common to each set of articu-
lated rods. At their other ends, the two sets (16, 17; 18,
10   19) of articulated rods are mounted on a platform (31) by
means of joints in such a way that those joints (23, 24)
which belong to one (16, 17) of the sets of articulated
rods are positioned on a line that is parallel to the cor-
responding line through the joints (26, 27) of the other
15   (18, 19) of the two sets of articulated rods. The inventive
concept also comprises the feature that these lines may be
coinciding, which implies that the joints (23, 24, 26, 27)
of both sets of articulated rods towards the platform (31)
are mounted along one and the same line.
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     Further, the above-mentioned parallel or coinciding lines
     are parallel to the axes of rotation of the arms (13, 14)
     on which the two sets (16, 17; 18, 19) of articulated rods
     are mounted. These axes of rotation are the same as the
25   axes of rotation of those actuators (10, 11) that drive
     these arms (13, 14). Further, in this embodiment, the third
     linkage (C) is mounted between a third actuator (12B) and
     the platform (31). The axis of rotation of the third actu-
     ator (12B) is chosen essentially perpendicular to the axes
30   of rotation of the other two actuators (10, 11), which
     causes the third arm (15) to swing in a plane perpendicular
     to the plane in which the two previously mentioned arms
     (13, 14) are swinging.

35   The inventive concept also comprises the feature of having
     the third actuator (12B) freely pivoting on the column (13)
     by means of a bearing (12A), the axis of rotation of which
     preferably coincides with the axes of rotation of the first

two actuators (10, 11). By then introducing a seventh arti-
culated rod (21C) to the platform (31), the degree of free-
dom added through said bearing (12A) may be locked. This
seventh articulated rod is suitably introduced in the third
5   set of articulated rods (20, 21, 21C), which is positioned
between the third pivoting arm (15) and the platform (31).
The third linkage (C) is configured such that at most two
out of three articulated rods included in the set of arti-
culated rods become parallel. To prevent rotations of the
10   platform (31) when the third arm (15) is swinging, the line
through the joints (29, 30C, 30) connecting the third set
of articulated rods (20, 21, 21C) to the platform (31)
should be parallel to the line through the joints (28A,
28C, 28B) connecting the third set of articulated rods (20,
15   21, 21C) to the third arm (15) and, at the same time, par-
allel to the axis of rotation of the third arm (15) and the
third actuator (12B). At the same time, this design will
cause the platform (31) to rotate the third actuator (12B)
on the bearing (12A) on the column 3, such that the third
20   arm (15) will always swing in a plane that is perpendicular
to the plane in which the first two arms (13, 14) are
swinging and, in addition, the third arm (15) will always
be situated midway between the first two arms (13, 14),
which provides a maximum working range for the robot.
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The invention also comprises mounting the third actuator
(12C) on another actuator (12D) that is capable of rotating
the third actuator around an axis that is essentially per-
pendicular to the axis of rotation of the second actuator
30   (12D).

It is also part of the inventive concept that at least two
of the sets (16, 17; 18, 19) of articulated rods are moun-
ted by means of said common joints (22, 25) on carriages
35   (40, 41) and that the manipulated platform (31) is caused
to move by controlling the positions of said carriages with
the aid of the actuators (10, 11). To avoid rotation of the
platform (31), the two sets (16, 17; 18, 19) of articulated

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rods are mounted on the platform (31) by means of joints
(23, 24; 26, 27) in such a way that a line (lead line)
through the joints (23, 24) belonging to one (16, 17) of
the two sets of articulated rods becomes parallel or coin-
5   cides with a corresponding line (lead line) through the
joints (26, 27) belonging to the other (18, 19) of the two
sets of articulated rods. Further, said two carriages (40,
41) are suitably mounted such that the movements of thereof
are carried out in a plane perpendicular to the above-
10   mentioned lead lines in a position when the platform (31)
is approximately in the centre of its working range. To
obtain a well utilized working range, these carriages
should, in addition, move along mutually parallel paths.

15   It is also part of the inventive concept to form the third
set of articulated rods (20, 21) either in the form of a
parallelogram with two joints at each end of the articula-
ted rods or in the form of a parallelepiped with two joints
at each end of the articulated rods or in the form of an
20   equilateral triangle or in the form of three articulated
rods, of which at most two may be parallel. The articulated
rods (20, 21) included in the third set of articulated rods
are mounted by joints (29, 30) on the platform (31) such
that a line between these joints becomes perpendicular to
·25   ·the ·above-·described· parallel· lines ·for the ·joints between
the first two sets (16, 17; 18, 19) of articulated rods and
the platform (31). In that way, rotation of the platform
(31) is avoided when the platform is manipulated.

30   According to the invention, for obtaining a large working
range of the embodiment of the robot with carriages (40,
41, 42), the third set (20, 21) of articulated rods may be
mounted on a lever-arm arrangement (15, 46, 44, 45) connec-
ted to the second and third carriages (41, 42). The task of
35   the lever-arm arrangement (45, 44, 46, 15) is to impart
large movements to the set (20, 21) of articulated rods
that is to move the manipulated platform (31) substantially
perpendicular to the direction of movement of the carriages

(40, 41, 42). Further, to obtain a maximum working range,
the linear paths (3A, 3B), on which the carriages are mov-
ing, are parallel and mounted such that the linkages (16,
17; 18, 19; 20, 21) are able to move between the linear

5   paths.

The inventive concept also comprises mounting on the mani-
pulated platform (31) a wrist with one, two or three axes.
The inventive concept also comprises using the robot as a

10 slave robot to carry out various operations inside a more
or less closed space (1). As a slave robot, the robot may
also be used as a wrist for a larger robot, in which case
the movements of the robot are synchronized to the move-
ments of the larger robot.

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BRIEF DESCRIPTION OF THE DRAWING

The invention will be explained in greater detail by means
of embodiments with reference to the accompanying drawing

20 wherein

    Figure 1   shows the type of working range (6) for which
                  the robot is especially suited,

25 Figure 2   shows a robot according to the invention with
                  three pivoting arms, wherein two of the axes of
                  rotation of the pivoting arms coincide so as to
                  give the robot a working range corresponding to
                  a whole ellipsoid or a sphere according to

30   Figure 1,

    Figure 3   shows a robot according to the invention with
                  two linear tracks, on which three carriages are
                  guided so as to obtain a gantry-like robot with

35   an elongated working range, wherein the front
                  and rear parts of the working range have the
                  shape of half an ellipsoid or half a sphere,

Figure 4   show a robot according to the invention with
                three pivoting arms, wherein two of the axes of
                rotation of the pivoting arms coincide and
                wherein the manipulated platform comprises two
5   angularly adjusted axles. On one axle, four of
                the platform joints are mounted with a coinci-
                ding axis,

Figure 5   shows a robot according to the invention with
10   four motors to impart an extra degree of free-
                dom of rotation to the manipulated platform,

Figure 6   shows an alternative to the configuration of
                the articulated rods for the movable platform
15   31.

DESCRIPTION OF THE PREFERRED EMBODIMENT

       Figure 1 schematically shows a frequently occurring case
20   when using industrial robots in a more or less closed
       space. The space is limited according to the figure by
       walls 1, on the inside of which operations such as welding,
       painting, grinding, cutting, measurement, machining, assem-
       bly, etc., are to be carried out, as indicated by the
25   arrows 2. To move the robot 4 into the space in question,
       there is used an external manipulator with a column struc-
       ture 3, which is capable of being manipulated at least up
       and down. To enable the robot to move the tool 5 to the
       positions and orientations shown by the arrows 2, a spheri-
30   cally or elliptically shaped working range 6 for the robot
       is required. In addition, the kinematics of the robot
       should be designed such that the tool holder, on which the
       tool 5 is mounted, points approximately radially outwards
       from the spherical/elliptical working range 6. In that way,
35   less demands will be made on the accessibility of the wrist
       that is to direct the tool 5 according to the arrows 2. As
       indicated in the figure, a conventional robot of serial
       type with so-called backward bending may be used. However,

such a robot has a plurality of disadvantages, for example
a high weigh, low accuracy (absolute, relative, temperature
dependence), considerable pliancy, long cycle times (low
acceleration, speed), and environmental sensitivity. To
5   overcome these disadvantages, a parallel-kinematic robot
may be used. However, the special requirement for the
working range requires an entirely new type of parallel
kinematics.

10   Figure 2 shows an embodiment of a parallel-kinematic in-
dustrial robot according to the invention, which meets the
kinematic requirements that are placed for an application
with a working range according to Figure 1. The column 3,
which is used to lower the robot into the space where is it
15   to operate, at the same time constitutes the base structure
of the robot, on which the actuators 10 and 11 are mounted.
The actuator 12B is articulately connected to the column 3
via the horizontal bearing 12A, which has its axis of ro-
tation coinciding with the centre line of the column 3. The
20   tool and the wrist, which are not shown in the figure, are
mounted on the manipulated platform 31. This platform is
manipulated by the actuators 10, 11 and 12 with the aid of
three linkages A, B and C. The linkage A for the actuator
10 comprises the lower arm 13, the joint 22, the links 16
25   and 17, and the joints 23 and 24 that are mounted on the
manipulated platform 31. In a corresponding way, the link-
age B for the actuator 11 comprises the lower arm 14, the
joint 25, the links 18 and 19, and the joints 26 and 27,
and the linkage C for the actuator 12B comprises the lower
30   arm 15, the joints 28A, 28B and 28C, the links 20, 21 and
21C as well as the joints 29, 30 and 30C. The joints 22 and
25 may be designed with two or three degrees of freedom and
the joints 23, 24, 26, 27, 28A, 28B, 28C, 29, 30 and 30C
may be designed with one, two or three degrees of freedom.
35   In the case of one degree of freedom, the axes of rotation
of the joints belonging to the same linkage must have coin-
ciding parallel axes of rotation. In the case of two deg-
rees of freedom, cardan joints or other angularly adjusted

joint configurations may be used, and in the case of three
degrees of freedom, universal joints or ball joints may be
used. To prevent stresses from being built into the robot
structure, for each articulated rod the joints at one end
5   should have three degrees of freedom and the joints at the
other end should have two or three degrees of freedom. If
an extremely light and fast robot is desired, all the
joints on the platform should be designed in the form of
ball joints. The joints 22 and 25 constitute a special
10 case, the task of these joints being to impart to the arti-
culated rods 16, 17 and 18, 19, respectively, common axes
of rotation relative to the arms 13 and 14, respectively.
In the case of ball joints, this can be achieved in the
simplest way by mounting two articulated rods on the same
15 ball or socket. The mounting is preferably performed such
that the articulated rods point inwards towards the centre
of the ball joint. In the case of a universal joint or a
cardan joint, the two articulated rods are suitably mounted
on the same bearing housing and in such a way that they
20 point inwards towards the kinematic centre of the joint.

When the actuator 12B is rotated, the lower arm 15 will
manipulate the platform 31, via the links 20, 21 and 21C,
up and down in the figure. This movement of the platform
25 will be a circular movement around the axis given by the
connecting line between the centre of the joint 22 and the
centre of the joint 25. If the joints 22 and 25 can manage
sufficiently large angular deflections (which is obtained
in a simple manner with universal joints), the platform 31
30 may be turned round more than 180 degrees by the lower arm
15. By then changing the angle between the lower arms 13
and 14 by means of the actuators 10 and 11, the connecting
line between the centre of the joint 22 and the centre of
the joint 25 will be moved in the radial direction relative
35 to the column 3, which results in a corresponding transla-
tion of the circular movement of the platform 31, which in
turn gives rise to an elliptic working range of the robot.

Then, if the lower arms 13 and 14 are turned synchronously
in the same direction, the elliptic working range will be
obtained in all directions radially out from the centre of
the column 3. This presupposes that the actuator 12B is

5   turned round on the bearing 12A such that the arm 15 is
always situated between the arms 13 and 14. That this is a
fact is guaranteed by the link structure in the linkage C.
By angularly adjusting at least one articulated rod (21C),
the arms 13 and 14 will rotate the arm 15, via the platform

10 31 and the links 20, 21 and 21C, such that the arm always
ends up midway between the arms 13 and 14. In this way, a
working range in the form of a complete ellipsoid is obtai-
ned around the column 3, which is the requirement made
according to Figure 1.

15

To prevent the platform 31 from rotating around its normal
when being manipulated, the joints 23 and 24 are mounted on
a line that is parallel to a line through the joints 26 and
27. These lines are then parallel to the axes of rotation

20 of the actuators 10 and 11. To obtain a symmetrical working
range, in addition, the axes of rotation of the actuators
10 and 11 should coincide. A further requirement to prevent
rotations of the platform around its normal is that a line
through the joints 29, 30C and 30 is parallel to a line

25 through the joints 28A, 28C and 28B (mounted on a T-struc-
ture of the arm 15), which in turn is parallel to the axis
of rotation of the actuator 12B. In order for the arm 15
always to be situated midway between the arms 13 and 14, it
is further required that the axis of rotation of the actua-

30 tor 12B be perpendicular to the axes of rotation of the
actuators 10 and 11. This in turn means that the line
through the joints 29, 30 and 30C is perpendicular to the
line through the lines 23 and 24 and the line through the
joints 26 and 27.

35

To reduce the weight of the robot, the actuators (suitably
the motors with gearing) for rotating the arms around may
be located at the upper part of the column 3, whereby, for

example, tube transmissions are used for bringing the rota-
tional movements down to the lower arms. It would then be
possible to regard the robot as a wrist for the manipulator
that brings the robot down into the space in which the ro-
5   bot is to work. In cases where it is desired to have a rig-
id and light wrist for a conventional robot or for a par-
allel-arm robot, the kinematic structure in Figure 2 could
be directly applicable.

10 Figure 3 shows an embodiment in which the column for lower-
ing the robot into the space in question is replaced by two
linear tracks 3A and 3B, which are mounted in parallel with
each other. On these tracks 3 there are three carriages 40,
41 and 42, which are driven by the actuators 10, 11 and 12,
15 respectively. The propulsion may be performed by means of
ball screws or belts, but another possibility is to use
linear motors. The three linkages A, B and C are here
connected to the carriages 40, 41 and 42. Thus, the joint
22 is mounted on the carriage 40, the joint 25 on the
20 carriage 41 and the joint 28 on the carriage 42 via the arm
15, the joint 46, the link 44 and the joint 45. This
arrangement for the joint 28 is used to obtain a pivoting
movement of the arm 15, which is articulately fixed to the
stand 43, which is mounted on the carriage 41. When the
25 carriages 42 and 41 move relative to each other, the arm 15
will carry out a pivoting movement, which imparts a circu-
lar movement to the platform 31 around the line connecting
the joint 25 to the joint 22. This line may then be trans-
ferred and rotated by moving the carriages 40 and 41 rela-
30 tive to each other, which causes an ellipsoidal movement
pattern.

To avoid rotations of the platform 31 around its normal
when the platform is manipulated, certain requirements are
35 made on the linkages A, B and C. Thus, the joints 23 and 24
and the joints 26 and 27 must be mounted on the platform 31
in such a way that a lead line through the lines 23 and 24
becomes parallel to a corresponding lead line through the

lines 26 and 27. These lead lines must then both be perpen-
dicular to a line through the lines 29 and 30. Further, it
is desirable for the carriages 40 and 41 to move along a
common plane or along parallel planes and for the movement
5   paths of the carriages to be parallel.

With regard to linkage C, the joint 28 may either be moun-
ted directly on the carriage 42 or, as in Figure 3, on a
lever arm 15, which is articulately mounted on the stand
10   43. The arm 15 may, of course, be driven by a rotating
actuator that is mounted on the carriage 41, but in that
case movable cabling may be used for feeding and control-
ling the actuator 12. One advantage of the arrangement of
Figure 3 is that the actuators 10, 11 and 12 are all fixed-
15   ly mounted and that therefore no movable cabling is requi-
red, which provides a higher reliability and a lower cost.

Figure 4 shows a variant of Figure 2, with the difference
that here the joints 23, 24 and 26, 27, respectively, are
20   not only mounted in parallel on the platform 31 but also
mounted along a straight line. This provides a possibility
of designing a simple platform, which only consists of two
angularly adjusted axles 31A and 31B, on which ball or rol-
ler bearings are mounted. The vertical axle 31A, on which
25   the joints 23, 24, 26 and 27 are mounted, is suitably par-
allel to the column 3 and hence parallel to the axes of ro-
tation of the actuators 10 and 11 whereas the angularly
adjusted axle 31B is suitably mounted in the horizontal
plane perpendicular to the vertical axis and parallel to
30   the axis of rotation of the actuator 12B.

When the actuator 12B is rotated, the lower arms 15 will
manipulate the platform 31 up and down in the figure via
the links 20, 21 and 21C. This movement of the platform
35   will be a circular movement around the axis given by the
connecting line between the centre of the joint 22 and the
centre of the joint 25. Then, by changing the angle between
the arms 13 and 14, by means of the actuators 10 and 11,

the connecting line between the joint 22 and the centre of
the joint 25 will be moved in a radial direction relative
to the column 3, which causes a corresponding translation
to be imparted to the circular movement of the platform 31,
5   which in turn gives rise to an elliptic working range of
the robot.

Then, if the lower arms 13 and 14 are rotated synchronously
in the same direction, the elliptic working range will be
10   obtained in all directions radially outwards from the cen-
tre of the column 3. This presupposes that the actuator 12B
is rotated around on the bearing 12A such that the arm 15
will always be situated between the arms 13 and 14. That
this is the case is guaranteed by the link structure of the
15   linkage C. This linkage comprises three articulated rods
20, 21C and 21, which are not parallel to one another, con-
trary to the corresponding link structure in Figure 2,
where two articulated rods are parallel. The object of this
three-link structure, besides locking two degrees of free-
20   dom of the platform, is also to lock the degree of freedom
that arises in the joint 12A. Thus, the three links 20, 21C
and 21 causes the arms 13 and 14 via the platform 31 and
the linkage C to rotate the actuator 12B around the joint
12A such that the arm 15 will always end up midway between
25   the arms 13 and 14. In this way, a working range is obtai-
ned in the form of a complete ellipsoid around the column
3, which is the requirement made according to Figure 1. The
three articulated rods 20, 21C and 21 are mounted between
the transverse platform axle 31B and the rod 15B on the arm
30   15. This mounting is made such that a line through the
joints 29, 30C and 30 is parallel to a corresponding line
through the joints 28A, 28C and 28B and such that these
lines are parallel to an axis of rotation of the actuator
12B. Further, these lines are perpendicular to the axes of
35   rotation of the actuators 10 and 11.

To prevent the platform 31 from rotating around its normal
when being manipulated, the joints 23 and 24 are mounted on

a line that is parallel to a line through the joints 26 and
27. These lines are then parallel to the axes of rotation
of the actuators 10 and 11. To obtain a symmetrical working
range, the axes of rotation of the actuators 10 and 11,
5   should, in addition, coincide.

Figure 5 shows another variant of the robot structure in
Figure 2. Here, the bearing 12A is replaced by a rotating
actuator 12D, which is capable of rotating the actuator 12C
10   around an axis perpendicular to the axis of rotation of the
actuator 12C and coinciding with a centre line of the col-
umn 3. This fourth actuator provides a possibility of im-
parting to the platform 31 a fourth degree of freedom, cap-
able of being manipulated, which consists of a rotational
15   movement around an axis extending through the joint 29. The
joint 29 is, in this structure, common to the articulated
rods 20 and 21, which at its other end is mounted with the
joints 28A and 28B, respectively, on the arm 15.

20   When the actuators 10 and 11 rotate the arms 13 and 14,
respectively, a radially directed movement, as roughly
viewed from the column 3, will be imparted to the platform
31. When the actuator 12C rotates the arm 15, roughly
viewed an upward/downward movement will be imparted to the
25   platform, and when the actuator 12D rotates the actuator
12C, a rotation of the platform 31 around an axis extending
through the joint 29 is obtained. The joint 29 has three
degrees of freedom and the joints 28A and 28B have one, two
or three degrees of freedom. In the case of one degree of
30   freedom, the joints 28A and 28B are mounted such that the
axes of rotation of these joints coincide and become paral-
lel to the axis of rotation of the actuator 12C.

Figure 6 shows an alternative to the configuration of the
35   articulated rods for the movable platform 31. Here, one
articulated rod (21) has been moved from the upper arm 15
to the upper arm 14 and one articulated rod has been re-
moved from the lower arm 15, which is now only connected to

the lower arm via a link (21C). At the same time, the bear-
ing 12A has been removed and the actuator 12B is now rota-
ted round by the actuator 11 through the fixed coupling 47.
The three links 18, 19 and 21 now have a common joint 25 to

5   the upper arm 14. In this design, the joints 26, 27 and 30
may also be eliminated (no degrees of freedom between the
links 18, 19, 21 and the platform 31). It should be pointed
out here that also the joints 24 and 23 may be simplified
and implemented with one degree of freedom along a common

10   axis. This latter simplification may, of course, also be
made possible for the triangular arrangements of links in
the other figures.

The invention comprises robots that are composed of a par-

15   allel-kinematic arm system driven by actuators. The arm
system comprises three parallel-working linkages A, B, C,
connecting the actuators 10, 11, 12B to the platform 31 to
be manipulated. Nearest the manipulated platform 31, the
linkages comprise articulated rods 16, 17, 18, 19, 20, 21

20   and it is the configuration of these articulated rods to-
gether with the configuration of the actuators 10, 11, 12
and the manipulated platform 31 that gives the robot its
unique properties. To lock all of the six degrees of free-
dom of the manipulated platform, a total of at least six

25   articulated rods are used. In this way, each articulated
rod will only need to transmit tensile and compressive for-
ces, which enables the articulated rods to be made very ri-
gid, light and accurate.

30   The articulated rods are mounted on the platform 31 with
the aid of joints 23, 24, 26, 27, 29, 30 that have one, two
or three degrees of freedom. The articulated rods are dis-
tributed such that each linkage comprises at least two ar-
ticulated rods to form sets of articulated rods 16, 17; 18,

35   19; 20, 21. To obtain as small forces as possible in the
articulated rods with respect to torsional moments of the
platform 31, those joints which belong to the same linkage
are mounted on the platform as far away from each other as

possible. A set of articulated rods belonging to the same
linkage is mounted with a set of joints 23, 24; 26, 27; 30,
31 on the manipulated platform 31. At the other end, in at
least two of the three sets of articulated rods, 16, 17;
5   18, 19, the articulated rods are mounted on a common joint
22, 25. In the case where the joints between a set of ar-
ticulated rods and the platform only have one degree of
freedom, the axes of rotation of those joints 23, 24; 26,
27; 20, 21 which belong to the same set of articulated rods
10 shall coincide. The common joint 22, 25, 28 for a pair of
articulated rods shall have two or three degrees of freedom
and the two or three axes of rotation of a common joint
should coincide in order that that kinematic model of the
robot shall not be too complex. To obtain the most favour-
15 able load picture in the common joint, the articulated rods
that are mounted thereon should point inwards towards the
centre of the joint, where the two or three axes of rota-
tion intersect one another.

20 The common joint 22, 25, 28 for a set of articulated rods
may be mounted either on a pivoting arm 13, 14, 15 or on a
carriage 40, 41, 42 moving along a path 3A, 3B. The pivot-
ing arms and the carriages are driven by actuators 10, 11,
12 which, via the three linkages A, B, C, give rise to a
25 combined transfer and rotational movement of the manipu-
lated platform 31.

Based on this basic design of a parallel-kinematic robot,
the invention comprises a number of advantageous embodi-
30 ments.

The inventive concept comprises mounting, in two of the
three sets of articulated rods, 16, 17; 18, 19, the links
included on pivoting arms 13, 14 with the aid of a joint
35 22, 25 that is common to each set of articulated rods. At
their other ends, the two sets of articulated rods 16, 17;
18, 19 are mounted on a platform 31 with joints in such a
way that those joints 23, 24 which belong to one of the

sets of articulated rods 16, 17 are positioned on a line
that is parallel to a corresponding line through the joints
26, 27 of the other 18, 19 of the two sets of articulated
rods. It is also part of the inventive concept that these
5   lines may coincide, which means that the joints 23, 24, 26,
27 of both sets of articulated rods towards the platform 31
are mounted along one and the same line.

Further, the above-mentioned parallel or coinciding lines
10   are parallel to the axes of rotation of those arms 13, 14
on which the two sets of articulated rods 16, 17; 18, 19
are mounted. These axes of rotation are the same as the
axes of rotation of the actuators 10, 11 that drive these
arms 13, 14. Further, in this embodiment, the third linkage
15   C is mounted between a third actuator 12B and the platform
31. The axis of rotation of the third actuator 12B is chos-
en essentially perpendicular to the axes of rotation of the
other two actuators 10, 11, which causes the third arm 15
to swing in a plane perpendicular to the plane in which the
20   two previously mentioned arms 13, 14 are swinging.

The inventive concept also comprises having the third actu-
ator 12B freely pivoting on the column 13 by means of a
bearing 12A, the axis of rotation of which preferably coin-
25   cides with the axes of rotation of the first two actuators
10, 11. By then introducing a seventh articulated rod 21C
for the platform 31, the degree of freedom added through
this bearing 12A may be locked. This seventh articulated
rod is suitably introduced in the third set of articulated
30   rods 20, 21, 21C that is located between the third pivoting
arm 15 and the platform 31. The third linkage C is confi-
gured such that a maximum of two of the three articulated
rods included in the set of articulated rods are parallel.
To prevent rotations of the platform 31 from arising when
35   the third arm 15 is swinging, the line though those joints
29, 30C, 30 that connect the third set of articulated rods
20, 21, 21C to the platform 31 should be parallel to the
line through those joints 28A, 28C, 28B that connect the

third set of articulated rods 20, 21, 21C to the third arm
15 and at the same time parallel to the axis of rotation of
the third arm 15 and the third actuator 12B. At the same
time, this design will cause the platform 31 to rotate the
5   third actuator 12A on the bearing 12A on the column 3, such
that the third arm 15 will always swing in a plane that is
perpendicular to the plane in which the first two arms 13,
14 are swinging, and, in addition, the third arm 15 will
always be located midway between the first two arms 13, 14,
10 which gives the robot a maximum working range.

It is also part of the invention that the third actuator
12C is mounted on another actuator 12D that is capable of
rotating the third actuator around an axis that is essen-
15 tially perpendicular to the axis of rotation of the second
actuator 12D.

The inventive concept also comprises mounting at least two
of the sets of articulated rods 16, 17; 18, 19 via said
20 common joints 22, 25 on carriages 40, 41 and causing the
manipulated platform 31 to move by controlling the posi-
tions of said carriages with the aid of actuators 10, 11.
To avoid rotations of the platform 31, the two sets of
articulated rods 16, 17; 18, 19 are mounted on the platform
25 31 via joints 23, 24; 26, 27 in such a way that a line, a
lead line, through those joints 23, 24 that belong to one
16, 17 of the two sets of articulated rods becomes parallel
to or coincides with a corresponding line, lead line,
through those joints 26, 27 that belong to the other 18, 19
30 of the two sets of articulated rods. Further, said two car-
riages 40, 41 are suitably mounted such that the movements
thereof are carried out in a plane perpendicular to the
above-mentioned lead lines in a position when the platform
31 is approximately in the centre of its working range. To
35 obtain a well utilized working range, the carriages should,
in addition, move along mutually parallel paths.

It is also part of the inventive concept to design the
third set of articulated rods 20, 21 either in the form of
a parallelogram with two joints at each end of the articu-
lated rod, or in the form of a parallelepiped with two

5   joints at each end of the articulated rod, or in the form
of an equilateral triangle, or in the form of three articu-
lated rods, of which at most two may be parallel. The arti-
culated rods 20, 21 included in the third set of articula-
ted rods are mounted via joints 29,30 on the platform 31

10 such that a line through these joints becomes perpendicular
to the parallel lines described above for the joints be-
tween the first two sets of articulated rods 16, 17; 18, 19
and the platform 31. In this way, rotation of the platform
31 is avoided when the platform is manipulated.

15

According to the invention, in order to obtain a larger
working range of the embodiment of the robot exhibiting
carriages 40, 41, 42, the third set of articulated rods 20,
21 may be mounted on a lever-arm arrangement 15, 46, 44, 45

20 connected to the second and third carriages 41, 42. The
task of the lever-arm arrangement 45, 44, 46, 15 is to im-
part large movements to the set of articulated rods 20, 21
that is to move the manipulated platform 31 substantially
perpendicular to the direction of movement of the carriages

25 40, 41, 42. Further, to obtain a maximum working range, the
linear paths 3A, 3B, on which the carriages are moving, are
parallel and mounted such that the linkages 16, 17; 18, 19;
20, 21 may move between the linear paths.

30 The inventive concept also comprises mounting on the mani-
pulated platform 31 a wrist with one, two or three axes. It
is also part of the inventive concept to use the robot as a
slave robot to carry out different operations inside a more
or less closed space 1. As a slave robot, the robot may al-

35 so be used as a wrist for a larger robot, in which case the
movements of the robot are synchronized to the movements of
the larger robot.